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An Assessment of Acoustic and Electronic Stethoscope Performance In the UH-60 Noise Environment

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U.S. Army helicopters used to provide aeromedical transport are extremely noisy (105 dB) and this prevents auscultation with current generation stethoscopes. Four stethoscopes were tested in simulated helicopter noise at 70 to 100 dB to determine the detection threshold of a normal heart and breath sound. They were unable to detect physiological sounds in high noise but they did differ in performance ($p < 0.001$); the best being the acoustic, followed by the three electronic stethoscopes. An electronic stethoscope modified with the Communications Ear Plug performed better ($p < 0.05$) at 70 and 80 dB than at higher noise levels, implying that ambient noise was amplified after entering the sensing head. The threshold of noise for the detection of heart and breath sounds was 85 dB and 75-80 dB, respectively, indicating the need for at least a 30 dB improvement in signal to noise ratio. Future research must measure the threshold for detection of abnormal sounds to determine if a greater improvement is required. If the electronic stethoscope is to be developed further, as seems most pragmatic, a suitable sensor will be needed before successful auscultation in rotary-wing aeromedical transport aircraft is possible.

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Introduction

The U.S. Army provides aeromedical transport services to its soldiers during all operations and training. In peacetime, the crews of aeromedical transport aircraft can also be called upon to support civilian populations. However, helicopters are extremely noisy and this, in conjunction with the vibration, prevents adequate auscultation with conventional stethoscopes (Hunt et al., 1991). Although ground transportation vehicles are quieter than helicopters, auscultation is still problematic; difficulty hearing breath and heart sounds in ambulances has been reported (Brown et al., 1997; Prasad et al., 1994).

Examination by auscultation is fundamental to the assessment of patients; it is rapid, mobile and simple. Rotary wing aeromedical transportation is principally concerned with the evacuation of those with acute injury or illness. In this emergency scenario, cardiac auscultation is helpful in assessing the integrity of the heart muscle, valves, and great vessels whilst blood pressure may be determined in conjunction with a pneumatic cuff. Auscultation of the lungs can be essential when confirming the placement of endotracheal tubes, or diagnosing conditions such as a pneumothorax, asthma, or pulmonary edema. Fixed wing medical transport flights are often of longer duration, and auscultation of body sounds becomes valuable in monitoring chronic conditions. The environment itself may lead to further medical complications; expansion of intestinal gases at high elevations can be monitored by auscultation of bowel sounds (Oxer, 1975). Other methods of monitoring respiratory and cardiac function exist and can replace the stethoscope; pulse oximeters may be used in the determination of blood pressure (Talke, 1991) and end-tidal carbon dioxide sensors can monitor respiration, but some of these may also fail in the harsh environment of the helicopter cabin (Low and Martin, 1988). In addition, they add complexity and, although alerting medical personal to the presence of a problem, they may not be capable of identifying the exact location of that problem. Unquestionably, there would be great benefit to successful, easy auscultation in the noisy medical transport environment.

The average breath sound pressure level (SPL) at an anterior-parasternal intercostal space has been measured at 26.3 dB (Hunt et al., 1990) and less than 75 dB within a stethoscope coupler (Zenk, 1994). It is estimated that the maximum at-the-ear ambient noise level at which unimpeded detection of heart sounds can occur is 70-75 dBA (Zacharias et al., 1993). Compared to this, the SPL in the cabin of a UH-60 during the cruise is 104 dBA and some rotary-wing aircraft exceed 110 dBA (Gasaway, 1986). Detecting body sounds is further complicated because the frequency spectra of breath and cardiac sounds is overlapped by that of helicopter noise, making simple electronic filtration of helicopter noise impossible (Poulton, Worthington, and Pasic, 1994).

Noise corrupts the physiological signal through four routes. Ambient noise may directly enter the listener's ears, or it may act upon the stethoscope tubing with transmission to the ears. Thirdly, noise and vibration may directly affect the sensing head of the stethoscope. Finally, ambient noise and vibrations enter and pass through the body of the patient. Limiting the noise and therefore increasing the signal-to-noise ratio will improve the ability of medical personnel to assess the patient. Although seemingly straightforward, no system has yet been created that can function in a helicopter.

In helicopters, ambient noise reaches damaging levels so medical personnel risk impairing their own hearing if they remove a hearing protection device (HPD) in order to don a stethoscope. The ideal stethoscope would, therefore, be incorporated into the HPD, eliminating the need to remove the HPD (Garner, 1991). In the military, the HPD is incorporated into a flight helmet in order to provide crash protection, and therefore the ideal in flight stethoscope needs to be compatible with the helmet (e.g., HGU-56/P). Active Noise Reduction (ANR) has not been integrated with this helmet and to do so would be costly. Another device able to protect hearing and allow accurate transmission of sound is the Communications Ear Plug (CEP) (Mozo, and Murphy, 1998). This has been integrated with the HGU-56/P and could be employed in combination with a stethoscope (Figure 1). Both ANR and CEP offer a reduction of noise at the ear and, in order to employ either of these systems, an electronic stethoscope is highly desirable. An electronic stethoscope also has the advantage of minimizing the potential for ambient noise to affect the signal during transmission from the stethoscope head to the ears.

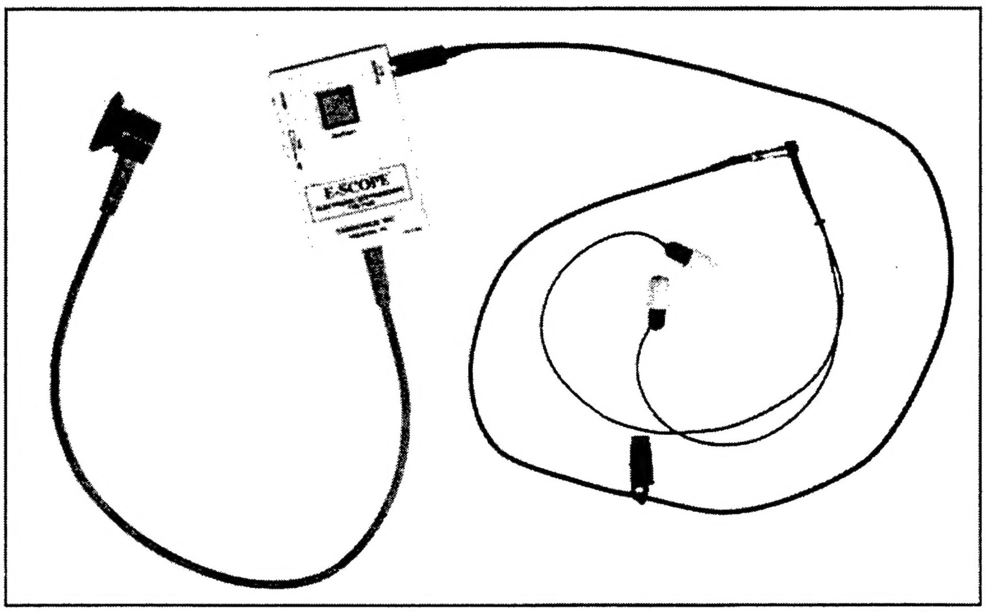

Figure 1. An electronic stethoscope interfaced with CEP.

Active and passive noise reduction techniques have been used to minimize signal corruption from ambient noise entering the stethoscope headpiece. Patel et al. (1998) were able to achieve a 15 dB reduction in ambient noise levels using least-mean-squares and normalized least-mean-squares algorithms and passive shielding of a standard stethoscope head. However, this technology has not yet been incorporated into a marketable product.

Ambient noise and vibrations resonating in the patient's body can blend with, and corrupt the signal before it is detected at the stethoscope head. There has been some success at increasing the signal to noise ratio by utilizing ANR at the stethoscope head, and this resulted in an apparent 10-15 dBA reduction in ambient noise levels (Zacharias et al., 1993), although this was in combination with ANR at the headset.

Although much work has been completed to date, there is no single clear definition of, or solution to, the problem. In addition, the newest generation of electronic stethoscopes is untested, and these may provide at least part of the solution. Improving auscultation could allow the U.S. Army's aeromedical flight crews to better assess the status of their patients, thus improving care. There would also be a secondary benefit in permitting better auscultation by those working in other noisy environments.

The objective of this study is to test a selection of electronic and acoustic stethoscopes in noise in order to establish baseline performance, identify potential solutions, and define the amount of improvement in signal to noise ratio required for accurate auscultation in Army helicopters. This is the first stage of an undertaking to develop a stethoscope capable of functioning during aeromedical transport.

Method

Devices tested

Four different auscultation devices were tested; (1) Littmann™ Master Classic Stethoscope (Figure 2, left), (2) Hewlett-Packard (now Agilent) Stethos™ electronic stethoscope (Figure 2, right), (3) Cardionics E-scope™ electronic stethoscope with normal ear pieces, and (4) Cardionics E-scope™ electronic stethoscope interfaced to the CEP[1] (Figure 1). The volume levels for the electronic stethoscopes were set at the midpoint level because at high volume the distortion and noise level was too great for comfort and at low levels they were too quiet.

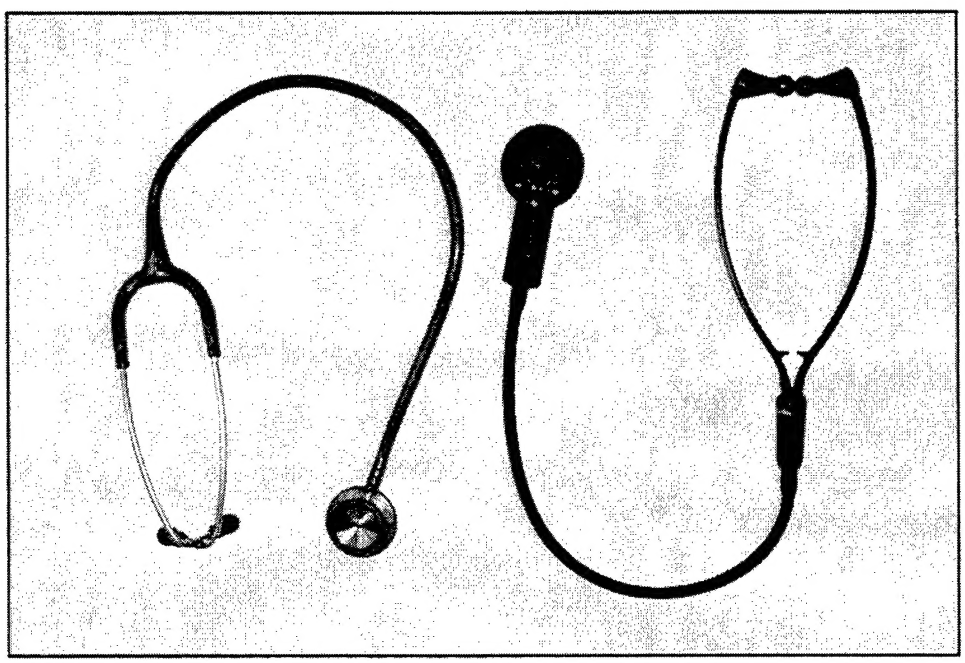

Figure 2. An acoustic stethoscope and conventional design electronic stethoscope.

[1] See Appendix B. Manufacturers List.

Human subjects

Ten U.S. Army flight medical personnel (doctors and physicians assistants) at Fort Rucker, Alabama, participated in the study. Subjects were briefed on the study design, screened by audiometry (those with hearing levels of 25 dB or lower from 0.125 to 6 kHz were permitted to participate), and signed an informed consent form. A posttest audiogram was collected at the end of each subject's participation. Noise levels were not allowed to exceed the maximum allowable limits of an 8-hour time-weighted-average of 85 dBA IAW DoD Instruction 6055.12 (1991). To ensure this, peak noise limits were capped at 100 dB allowing 15 minutes exposure. Although subjects were in the chamber for 30 minutes, they were exposed to that level for less than 15% of the time. The stethoscopes, CEP and helmet added an extra degree of protection, but this additional safety margin was not used in the determination of exposure time limits.

Equipment

The real-ear test procedure utilized Tucker-Davis Technologies (TDT) psychoacoustic test modules controlled by a general-purpose personal computer using custom-written software to control the cardiac/breath sound detection paradigm. Figure 3 presents a schematic of the experimental setup.

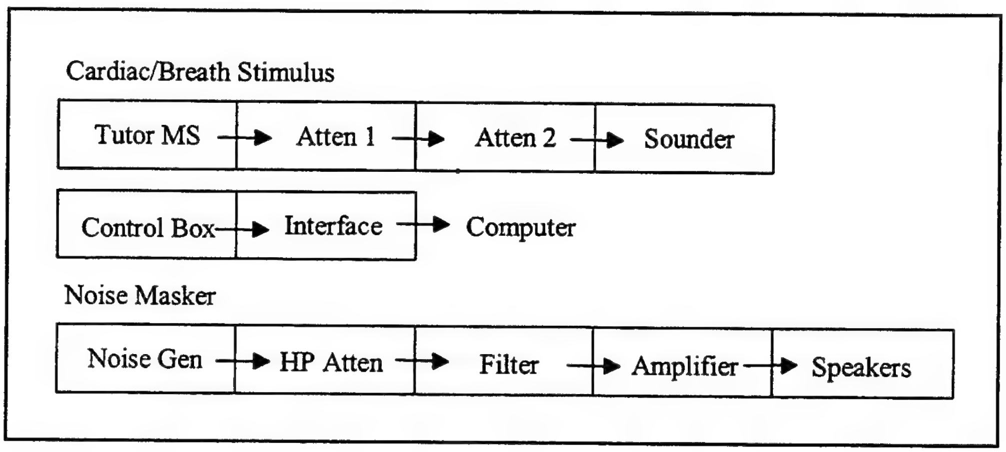

Figure 3. Experimental setup. Schematic representation of the equipment used for cardiac/breath detection threshold measurements.

A Wolff Tutor MS Data Selector sound simulator was used to simulate cardiac and breath sounds. This device consists of a control pad for selecting various cardiac or breath sounds, a knob for adjusting volume levels, plug-in modules that store a variety of heart or breath sounds, and a pliable pad sounder that reproduces the selected sounds. The Basic Heart Sounds and the Breath Sounds plug-in modules were used to deliver an apex heart beat (sound number 1) and a vesicular breath sound (sound number 2). The Tutor MS simulator volume was set to the maximum level resulting in a 100.5 dB peak SPL cardiac sound and 109.0 dB peak SPL breath sound. The output of the Tutor MS sound simulator was connected to two TDT PA4

Programmable Attenuators connected in series. The output of the attenuators was fed through a connection panel to a 3.20 m W × 2.83 m D × 1.97 m H reverberant chamber configured for ANSI S12.6-1997 (1997) hearing protector device evaluations and then to the MS Tutor sounder. The sounder was placed in a ring of sound absorbent foam which served both to shield the side of the sounder from the noise field and to provide a convenient place on which the subjects could rest their arms during auscultation.

Broadband noise was generated by a Brüel & Kjær Model 1405 noise generator, filtered through a General Radio Model 1925 Third-octave Multifilter and fed to a Hewlett-Packard (HP) Model 350D (manual) attenuator and then to a Altec-Lansing Model 1594C Power Amplifier. The output of the amplifier was fed into the reverberant chamber to three Altec Model 612C speakers. The level of the noise in the reverberant chamber was adjusted by means of the HP manual attenuator.

Procedure

A normal apex cardiac and a normal broncho-vesicular breath sound were used. A TDT RBOX response box was used by the subject to adjust the level of the cardiac or breath sound (via the programmable attenuators and TDT PI2 Advanced Parallel Interface Adapter Module). Each subject was given the opportunity to listen to each of the sounds before entering the test chamber and to practice the psychophysical procedure before the start of testing. The subject was instructed to reduce the level of the cardiac/breath sound (via a control pad) until it "becomes just inaudible," then raise the level of the sound until it "becomes just audible." The subject terminated the trial by pressing a button on the control pad. During training and data collection, the threshold was determined as the average of four consecutive judgments at a single test signal, with the condition that the range of these four judgments be no greater than five decibels. If response variability was large and this criterion was not reached after 20 responses, the testing was paused and the subject was reinstructed on the use of the response box and reminded of the listening strategy. Subjects seldom required more than 20 trials to reach criterion, with the vast majority of thresholds collected with less than six responses.

During actual data collection, after the subject was seated in the test chamber with the auscultation device sensor centered on the simulator pad, broad-band noise was presented initially at 70 dB SPL. The programmable attenuators initially were set so that the cardiac or breath sounds was clearly audible. Following determination of the threshold in the presence of the 70 dB SPL broadband noise, thresholds were determined in a like manner in the presence of 80, 90, and 100 dB SPL broadband noise. Within each stethoscope, cardiac sounds were measured first since they were somewhat easier for the subjects to hear because of their distinctive pattern. A brief rest interval was taken when the subjects changed to a different type of stethoscope.

Two way repeated measures analysis of variance (ANOVA) and pairwise multiple comparison (Duncan's Method) of the stethoscope types for both the heart and breath sound thresholds were performed with the probability of a Type I error set at 0.05 for each analysis.

Results

The SPL of the heart and breath sound signals are shown in the Table. These were calculated from the amount of attenuation applied by the subjects, and the complete data set is shown in Appendix A. The heart sound was easier to hear than the breath sound. At 90 dB, the subjects had increasing difficulty in detecting the breath sound, and at 100 dB, they were not able to detect the breath sound. Data collection attempts for the breath sound at 100 dB were discontinued after the first three subjects, and therefore, the results for this SPL/breath sound combination are not included in the analysis. Across the noise levels, there was a significant difference in performance among the stethoscopes as a group ($p < 0.001$). The best performing stethoscope was the Littmann, followed by the CEP modified E-scope, the E-scope and then the Stethos.

Table

Mean (±1SD) SPL of just audible heart/breath sounds in a range of noise levels.

Noise level (dB)	Sound	Stethoscope Type			
		Littman	CEP	E-scope	Stethos
70	Heart	62.8 ± 6.9	67.6 ± 4.1	73.1 ± 4.5	80.9 ± 5.4
80	Heart	66.9 ± 5.0	73.8 ± 3.5	76.0 ± 5.2	85.9 ± 5.5
90	Heart	71.6 ± 4.2	79.3 ± 3.1	80.0 ± 4.1	91.2 ± 4.6
100	Heart	75.9 ± 4.5	86.0 ± 5.4	84.4 ± 5.2	95.9 ± 4.3
70	Breath	68.1 ± 4.7	68.4 ± 3.8	78.2 ± 7.5	79.4 ± 2.5
80	Breath	76.0 ± 3.6	78.9 ± 3.5	85.3 ± 5.7	89.6 ± 2.5
90	Breath	85.1 ± 3.1	90.7 ± 4.3	90.7 ± 4.4	97.4 ± 2.5

The simple comparison of the group is informative, but a more detailed examination of the differences between individual stethoscopes reveals that these depend on the level of noise that is present in the chamber (Breath: $p < 0.001$ and Heart: $p = 0.021$). Comparison of the Cardionics stethoscope and CEP modified Cardionics stethoscope for both heart and breath sounds reveals a consistent performance change as the SPL rises. There is a statistically significant difference ($p < 0.05$) in performance at 70 dB for the heart sound and at 70 and 80 dB for the breath sound and no difference ($p > 0.05$) in performance at higher noise levels. This change is not seen in comparisons of other stethoscopes.

The effect of increasing noise levels on the ability of all stethoscopes to detect heart and breath sound signals is shown graphically in Figures 4 and 5. The rate of increase in required signal strength with increasing chamber noise levels was greater for the breath sound than the heart sound; 8.7 versus 4.8 dB per 10 dB rise in chamber noise. In both figures, the relative

change in performance of the Cardionics stethoscope and CEP modified Cardionics stethoscope with increasing noise is evident.

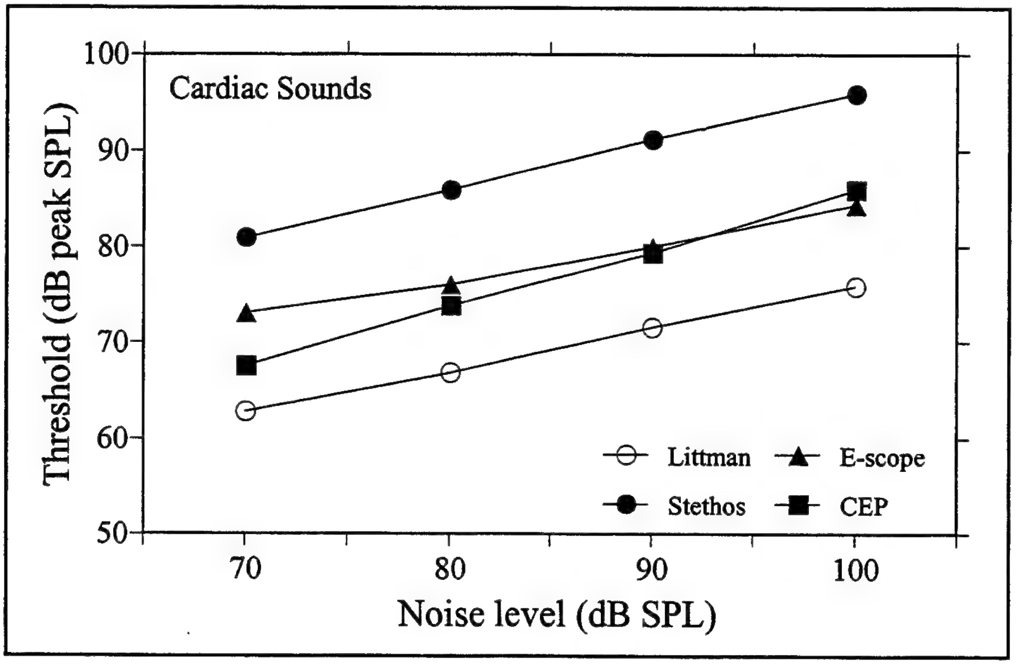

Figure 4. Mean SPL of just audible heart sounds in a range of noise levels.

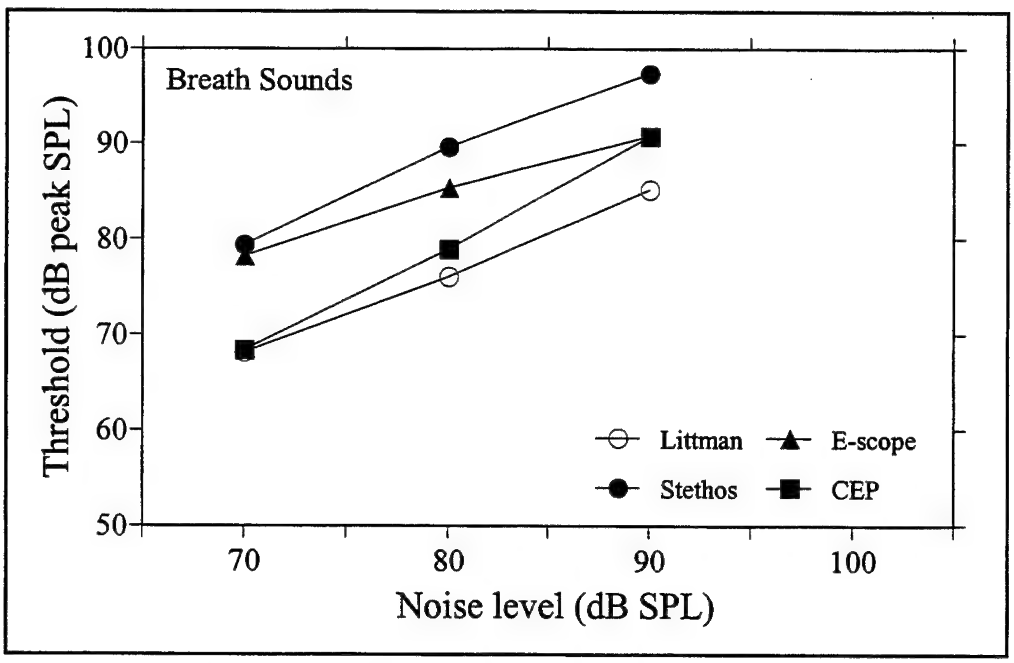

Figure 5. Mean SPL of just audible breath sounds in a range of noise levels.

Discussion

The difference in ease of detection between the two physiological sounds is notable. It is possible to hear the heart sound in 100 dB noise, but despite the ability to raise the SPL of the breath sound, it is only possible to detect it when the noise does not exceed 90 dB. Even so, at some time during the study, using all devices, subjects had to alter the SPL of the heart and breath sounds to be louder than that normally found in the stethoscope head in order to allow detection. The level at which physiological sounds were detected accords well with earlier work using stethoscopes in noise. In our study, the acoustic stethoscope performed the best in noise, although Russotti et al. (2000) found a less clear result. In their study, the acoustic stethoscope was as good as the E-scope at detecting the normal heart sound in noise, but it was worse at detecting breath sounds. Russotti et al. also examined the ability to detect abnormal physiological sounds. Here the acoustic stethoscope performed poorly in detecting both abnormal heart sounds and abnormal breath sounds. Whilst the electronic stethoscopes performed better, abnormal heart and breath sounds still proved more difficult to detect than normal sounds.

In the present study, subjects had to have the breath sound louder initially, and had to increase the SPL of the breath sound at a greater rate in order to continue to detect the sound. The frequency spectrum for heart sounds is concentrated below 150 Hz (Arnott, Pfeiffer, and Tavel, 1984) and for breath sounds it lies between 0.5-1 kHz (Gavriely et al., 1995). Examination of the UH-60 noise spectrum (Figure 6) reveals the SPL to be higher at the heart frequencies than the breath frequencies and, as a result, greater masking of the heart sound might be expected. The characteristic first and second sounds probably make the heart beat more discernable against the background noise and this accounts for it being detectable at higher sound pressure levels. However, the abnormal additional sounds are less commonly heard and often quieter, making masking by noise more likely.

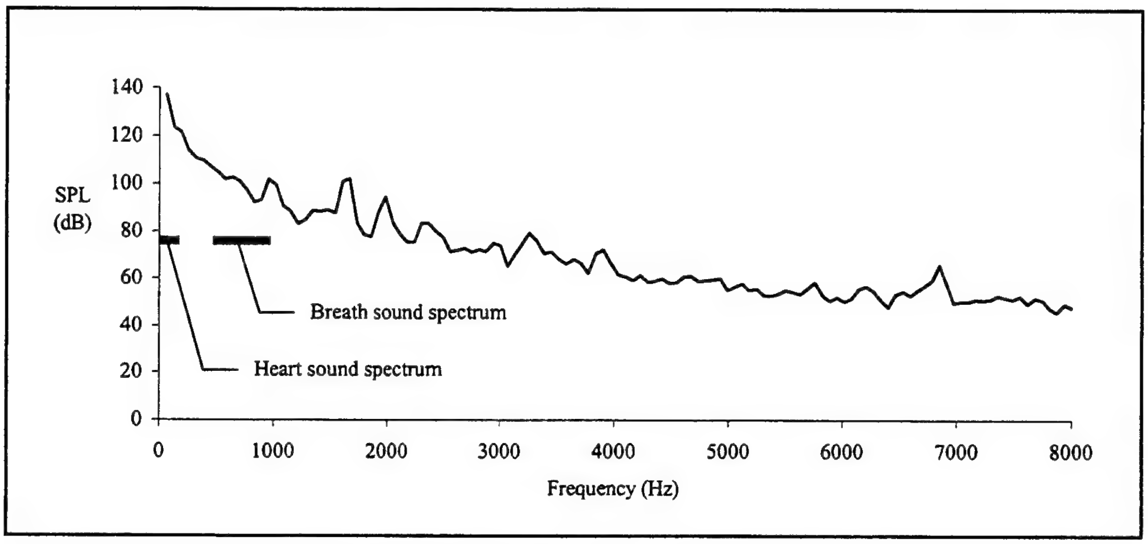

Figure 6. UH-60 noise spectrum.

There were some interesting differences in the performance of the different devices. Exposure to the high sound pressure levels used in this experiment (compared to a routine clinical setting) seems to be the most challenging to the electronic stethoscopes. At low noise levels, the integral shielding appears effective in cutting out unwanted noise, but as the SPL of the background noise increases, the signal becomes increasingly corrupt. This may simply be due to noise entering the system and adding to the reference signal. There is certainly some evidence for this in that there is an almost linear rise in the signal strength with increasing noise. However, the CEP modified E-scope has better performance at lower noise levels than the standard E-scope, but the performance of the two stethoscopes is the same at higher SPLs. The CEP system was worn with the HGU-56/P helmet and, with the better hearing protection provided, there is less incursion by ambient noise. This benefit should be the same at all noise levels as the same degree of noise attenuation is present from 70 to 100 dB. This implies that it is not simply a matter of noise entering the system but that it is also amplified by the system before delivery to the ear. For sound to be amplified, it must enter the system before processing and, therefore, the stethoscope sensing head appears to be the route of entry for noise that causes the greatest problems at the higher SPLs. A sensor capable of detecting physiological sounds whilst rejecting ambient noise is a key requirement for further stethoscope development.

The current threshold of environmental noise for the detection of heart and breath sounds is around 85 dB and 75-80 dB, respectively, with an electronic stethoscope. In the UH-60, a 15 dB improvement in the system would be required just to detect normal heart sounds, and a 30 dB improvement to detect normal breath sounds. The larger value for breath sounds is a function of both the lower detection threshold and the greater rate of increase signal strength that is required as noise increases. Tracheal breath sounds have greater power as a result of less attenuation by body tissue (Gavriely, Palti, and Alroy, 1981), and they could be used for monitoring patient status. If they were used, less improvement in current stethoscopes would be required, but the need to differentiate between the right and left lungs, e.g., to verify endotracheal tube placement, would not be addressed.

Studies comparing electronic and acoustic stethoscopes have also shown that most medical personnel favor acoustic stethoscopes in clinical settings (Grenier et al., 1998). Given this, and the better performance of the acoustic stethoscope in this study, it would seem the best choice for use in noise. They are, however, probably close to their maximum potential performance and yet are still not capable of functioning in the UH-60. Strategies such as ANR, filtering, and shielding may be easier to adapt to electronic stethoscopes (rather than to acoustic stethoscopes) and they seem to have the most potential for further development.

This study only addressed the detection of heart and breath sounds where the sound was known to be present and the subject had the opportunity to learn the sound. Real world auscultation is more problematic. In endotracheal tube placement, the desired outcome is to determine the presence or absence of a sound, and operating at the threshold of detection is undesirable. Abnormal heart sounds, in particular, are more difficult to detect, even in quiet environments; enhanced signal quality, as well as strength, will be required. Taken together, these suggest that a stethoscope capable of full function in noise must be improved more than is required for uncomplicated detection.

Conclusion

The current generation stethoscopes assessed in the study are unable to detect physiological sounds in high noise. In order to achieve reliable auscultation of normal physiological sounds, stethoscopes will need at least a 30 dB improvement in signal to noise ratio. Future research is needed to measure the threshold for detection of abnormal sounds in order to determine if a greater improvement is required. In the electronic stethoscope, the sensing head was identified as one component that decreased the capability of the device to detect sounds in noise. If it is to be developed further, as seems most pragmatic, a suitable sensor will be needed before there can be successful auscultation in rotary-wing aeromedical transport aircraft.

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Appendix A.

Experimental data and statistical analysis

Table A-1.
Attenuation and heart sound SPL (dB) in noise in order for the sound to become just audible.

Stethoscope	Subject	Attenuation				Heart sound SPL			
		70 dB	80 dB	90 dB	100 dB	70 dB	80 dB	90 dB	100 dB
Littman	1	38.67	34.67	34.00	31.00	61.83	65.83	66.50	69.50
Littman	2	42.00	39.33	35.00	29.00	58.50	61.17	65.50	71.50
Littman	3	44.67	39.00	32.00	28.33	55.83	61.50	68.50	72.17
Littman	4	35.33	31.67	29.00	24.67	65.17	68.83	71.50	75.83
Littman	5	49.33	38.67	30.33	21.33	51.17	61.83	70.17	79.17
Littman	6	32.33	30.67	26.67	21.00	68.17	69.83	73.83	79.50
Littman	7	27.67	24.00	23.00	17.67	72.83	76.50	77.50	82.83
Littman	8	36.67	34.33	30.33	26.33	63.83	66.17	70.17	74.17
Littman	9	28.67	28.33	26.00	27.67	71.83	72.17	74.50	72.83
Littman	10	41.33	35.67	23.00	19.33	59.17	64.83	77.50	81.17
Stethos	1	24.67	21.67	17.00	11.67	75.83	78.83	83.50	88.83
Stethos	2	27.67	22.67	16.67	8.33	72.83	77.83	83.83	92.17
Stethos	3	23.00	15.67	11.00	9.67	77.50	84.83	89.50	90.83
Stethos	4	20.00	8.00	6.00	0.67	80.50	92.50	94.50	99.83
Stethos	5	14.33	10.67	6.00	0.00	86.17	89.83	94.50	100.50
Stethos	6	18.67	16.67	6.67	1.00	81.83	83.83	93.83	99.50
Stethos	7	11.33	8.33	7.00	5.00	89.17	92.17	93.50	95.50
Stethos	8	22.33	15.67	10.67	2.67	78.17	84.83	89.83	97.83
Stethos	9	21.33	18.00	8.67	6.67	79.17	82.50	91.83	93.83
Stethos	10	12.33	8.33	3.33	0.00	88.17	92.17	97.17	100.50
E-scope	1	30.00	27.33	26.67	22.33	70.50	73.17	73.83	78.17
E-scope	2	20.67	16.33	16.67	11.67	79.83	84.17	83.83	88.83
E-scope	3	25.67	21.33	21.67	23.33	74.83	79.17	78.83	77.17
E-scope	4	28.67	33.67	24.67	17.67	71.83	66.83	75.83	82.83
E-scope	5	23.00	22.00	22.00	14.00	77.50	78.50	78.50	86.50
E-scope	6	35.00	28.00	18.67	17.00	65.50	72.50	81.83	83.50
E-scope	7	26.00	20.00	20.00	12.67	74.50	80.50	80.50	87.83
E-scope	8	33.00	28.33	20.00	15.67	67.50	72.17	80.50	84.83
E-scope	9	28.67	27.00	22.67	20.33	71.83	73.50	77.83	80.17
E-scope	10	23.67	20.67	12.33	6.33	76.83	79.83	88.17	94.17
CEP	1	38.67	35.00	28.00	27.00	61.83	65.50	72.50	73.50
CEP	2	29.33	23.67	19.33	10.00	71.17	76.83	81.17	90.50
CEP	3	35.33	29.00	25.00	20.33	65.17	71.50	75.50	80.17
CEP	4	34.67	27.00	20.00	13.00	65.83	73.50	80.50	87.50
CEP	5	31.33	25.67	19.67	15.67	69.17	74.83	80.83	84.83
CEP	6	30.00	23.00	22.00	10.33	70.50	77.50	78.50	90.17
CEP	7	29.33	24.00	18.33	12.00	71.17	76.50	82.17	88.50
CEP	8	34.67	27.67	18.33	11.00	65.83	72.83	82.17	89.50
CEP	9	27.00	24.33	19.33	15.00	73.50	76.17	81.17	85.50
CEP	10	39.00	27.33	21.67	11.00	61.50	73.17	78.83	89.50

Table A-2.
Attenuation and breath sound SPL (dB) in noise in order for the sound to become just audible.

Stethoscope	Subject	Attenuation			Breath sound SPL		
		70 dB	80 dB	90 dB	70 dB	80 dB	90 dB
Littman	1	44.67	34.00	26.67	64.33	75.00	82.33
Littman	2	42.33	33.33	23.33	66.67	75.67	85.67
Littman	3	44.67	35.00	24.67	64.33	74.00	84.33
Littman	4	42.00	31.67	24.33	67.00	77.33	84.67
Littman	5	46.33	41.33	29.00	62.67	67.67	80.00
Littman	6	41.33	32.67	24.00	67.67	76.33	85.00
Littman	7	34.00	28.67	24.00	75.00	80.33	85.00
Littman	8	43.67	33.00	23.33	65.33	76.00	85.67
Littman	9	32.33	30.67	22.33	76.67	78.33	86.67
Littman	10	37.33	29.33	17.00	71.67	79.67	92.00
Stethos	1	31.33	20.67	13.67	77.67	88.33	95.33
Stethos	2	31.00	18.67	11.00	78.00	90.33	98.00
Stethos	3	32.00	21.67	13.00	77.00	87.33	96.00
Stethos	4	29.67	21.67	14.67	79.33	87.33	94.33
Stethos	5	28.00	17.33	12.67	81.00	91.67	96.33
Stethos	6	31.67	21.33	11.33	77.33	87.67	97.67
Stethos	7	24.33	19.67	10.67	84.67	89.33	98.33
Stethos	8	31.67	22.00	11.67	77.33	87.00	97.33
Stethos	9	29.33	15.33	12.33	79.67	93.67	96.67
Stethos	10	27.33	15.67	5.33	81.67	93.33	103.67
E-scope	1	36.67	28.00	20.33	72.33	81.00	88.67
E-scope	2	20.67	12.33	13.00	88.33	96.67	96.00
E-scope	3	32.67	19.00	12.00	76.33	90.00	97.00
E-scope	4	33.33	26.33	22.00	75.67	82.67	87.00
E-scope	5	25.00	19.67	16.67	84.00	89.33	92.33
E-scope	6	39.00	29.67	21.33	70.00	79.33	87.67
E-scope	7	34.67	28.67	22.33	74.33	80.33	86.67
E-scope	8	41.00	28.33	21.67	68.00	80.67	87.33
E-scope	9	23.67	25.33	21.33	85.33	83.67	87.67
E-scope	10	21.33	19.33	12.00	87.67	89.67	97.00
CEP	1	48.33	35.33	24.33	60.67	73.67	84.67
CEP	2	40.33	28.00	16.33	68.67	81.00	92.67
CEP	3	43.33	32.33	23.00	65.67	76.67	86.00
CEP	4	42.33	33.00	23.33	66.67	76.00	85.67
CEP	5	37.67	27.67	15.67	71.33	81.33	93.33
CEP	6	42.67	29.33	15.33	66.33	79.67	93.67
CEP	7	35.33	22.67	11.00	73.67	86.33	98.00
CEP	8	41.33	30.00	20.33	67.67	79.00	88.67
CEP	9	36.33	31.00	17.00	72.67	78.00	92.00
CEP	10	38.67	31.33	16.67	70.33	77.67	92.33

Table A-3.
Two Way Repeated Measures ANOVA for heart sound.

Source of Variation	DF	SS	MS	F	P
Subject	9	1197.300	133.033		
Stethoscope	3	7517.410	2505.803	54.432	<0.001
Stethoscope x Subject	27	1242.966	46.036		
Noise Level	3	4643.837	1547.946	131.085	<0.001
Noise Level x Subject	27	318.835	11.809		
Stethoscope x Noise Level	9	149.335	16.593	2.343	0.021
Residual	81	573.619	7.082		
Total	159	15643.303	98.386		

Table A-4.
Two Way Repeated Measures ANOVA for breath sound.

Source of Variation	DF	SS	MS	F	P
Subject	9	686.779	76.309		
Stethoscope	3	2735.779	911.926	27.917	<0.001
Stethoscope x Subject	27	881.964	32.665		
Noise Level	2	6103.093	3051.546	329.113	<0.001
Noise Level x Subject	18	166.897	9.272		
Stethoscope x Noise Level	6	261.129	43.522	10.566	<0.001
Residual	54	222.436	4.119		
Total	119	11058.078	92.925		

Appendix B.

Manufacturers List.

Littmann™ Master Classic Stethoscope
3M Health Care
St. Paul, MN 55144

Hewlett-Packard Stethos™ Electronic Stethoscope
Hewlett-Packard Company
Medical Products Group
3000 Minuteman Rd
Andover, MA 018100

Agilent™ Headquarters
395 Page Mill Rd.
P.O. Box #10395
Palo Alto, CA 94303

E-scope™ Electronic Stethoscope
Cardionics, Inc.
910 Bay Star Blvd.
Webster, TX 77598

Communications Ear Plug
Communications and Ear Protection, Inc.
PO Box 311174
101 Development Ave
Enterprise, AL 36331-1174

Tutor MS
Wolff Industries
4080 Bennett Road
Suite A
Toledo, OH 43612

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